# RESEARCH MEMORANDUM

## NACA INVESTIGATION OF FUELS CORRESPONDING TO SPECIFICATION AN-F-58

## RESULTS OF STUDIES IN SINGLE COMBUSTORS OF J-33, J-34, J-35 AND NENE TURBOJET ENGINES

By Cleveland Laboratory Staff

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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## SUMMARY

The NACA is engaged in a program to evaluate the performance of fuels conforming to AN-F-58 specification in both full-scale engines and single combustors. This research memorandum constitutes an interim report on the results obtained on single cosibustors.

## INTRODUCTION

The scope of the investigations on single combustors was, by mutual agreement with the Military Services, to include the following phases:

(1) The effects of the variations allowable under specification AN-F-58 in respect to (a) the high boiling components and (b) the aromatic content were to be determined on single combustors. The performance parameters to be examined included combustion efficiency, altitude operational limits, and carbon formation. The first two parameters were to be determined on J-33, J-34, J-35, J-47, and Nene combustors. The carbon forming tendencies of the various fuels were to be determined on a J-33 combustor.

(2) The influence of reducing the Reid vapor pressure from 5 pounds per square inch to 1 pound per square inch on ignition and starting was to be determined on a J-33 combustor.

(3) The influence of small concentrations of organic disulfides on the carbon forming tendency of an AN-F-58 fuel was to be determined on a J-33 combustor.

This report contains a brief outline of the results obtained at the NACA Lewis Laboratory on the J-33, J-34, J-35, and Nene combustors.

## DISCUSSION OF RESULTS

Four fuels were used in tests of each combustor. One of these was the design fuel for the individual engine and the other three were fuels corresponding to specification AN-F-58 but differing in boiling range and aromatic content. The inspection properties of AN-F-32 fuel and the various blends of AN-F-58 fuel are tabulated in table I. One of these, hereafter designated 48-249, was an AN-F-58 fuel as received from the supplier. One of the other two (designated 48-258) contained 8 percent by volume of number 3 fuel oil. The second fuel (designated 48-279) was prepared by blending 48-249 with 8 percent by volume of number 3 fuel oil and 13 percent by volume of redistilled hydroformate bottoms reported to be 90-95 percent aromatic.

J-33-A-23 Combustor. - The normal performance of AN-F-32 and the three blends of AN-F-58 fuel was obtained on the J-33-A-23 single combustor at the inlet conditions simulating engine operation for a range of speeds from 5600 to 11,750 rpm, at altitudes from 5000 to 60,000 feet, and at flight Mach numbers of 0.0 and 0.6. A summary of the results obtained on the engine are shown on figure 1 for 60 and 90 percent normal rated speed, for Mach numbers of 0.0 and 0.6 and altitudes from 5000 to 60,000 feet. As can be seen from this figure, increasing the final boiling point of the AN-F-58 fuel from 560° F (fuel 48-249) to 590° F (fuel 48-258), without changing the aromatic content, had little or no effect upon combustion efficiency. Increasing the final boiling point of the AN-F-58 fuel to 590° F and the aromatic content from 19 (fuel 48-249) to 29 (fuel 48-279) percent resulted in slightly lower combustion efficiency at altitudes below 55,000 feet and slightly higher efficiencies from there up to 60,000 feet at 90 percent normal rated speed and Mach numbers of 0.0 and 0.6. The trend was the same at 60 percent of normal rated speed but the curves crossed at about 40,000 feet. At 60,000 feet the use of AN-F-32 resulted in efficiencies up to 16 percent higher, depending upon the engine speed and Mach number, than those of the low end point, low aromatic content AN-F-58 fuel (48-249).

J-35-C-3 Combustor. - The normal performance of AN-F-32 and the three blends of AN-F-58 fuel was obtained on the J-35-C3 single combustor at the inlet conditions- simulating engine operation for a range of speeds from 3000 to 8000 rpm, at altitudes from 10,000 to 60,000 feet, and at flight Mach numbers of 0.0 and 0.6. A summary of the results obtained on this engine are shown on figure 2 for 52 and 85 percent normal rated speed, for Mach numbers of 0.0 and 0.6, and altitudes from 10,000 to 60,000 feet. For the fuels tested, no blowout limits were encountered at rotor speeds above 65 percent rated speed over the altitude range investigated. A a Mach number of 0.0 and at 52 percent normal rated speed it can be seen that the fuels tested did not exhibit an appreciable difference in blowout limit; however, at a Mach number of 0.6 the high end point aromatic blend (48-279) and AN-F-32 had the highest blowout limits, while the high-end point paraffinic blend (48-258) had the lowest limit. The low-end point AN-F-58 fuel (48-249) had a blowout limit intermediate between 48-258 and 48-279. In general, 48-249 and the paraffinic blend (48-258) gave the higher combustion efficiencies, with small differences at the higher engine speed but appreciable differences at the lower engine speed.

Carbon deposition. - The carbon deposition of AN-F-52 and the three blends of AN-F-58 fuel was investigated in the J-33 single combustor at running times of 2, 4, 6, and 10 hours at simulated engine operating conditions of 90 percent normal rated engine speed
7 snd an altitude of 20,000 feet. The effect of running time on carbon deposition and a comparison of the amount of carbon deposited for each fuel can be seen on figure 3. Carbon deposition increased with increase in boiling range at constant aromatic content of the AN-F-58 fuels. Carbon depositfon also increased with increase in aromatic content with constant boiling range for the AN-F-58 fuels. Values of carbon deposition obtained with AN-F-52 were exceeded only by the values obtained with the AN-F-58 hating the 590° F end point and 29 percent aromatics.

J-34-4B Combustor. - The altitude operational limits of the J-34-4B combustor were obtained for AN-F-28 and the three blends of AN-F-58 at a ram-pressure ratio of 1.04 and a corrected engine speed from 6000 to 12,500 rpm. As can be seen from figure 4, which is a summary of these tests, raising the upper end boiling temperature (fuels 48-249 and 48-258) has practically no influence on the altitude limits of AN-~-58. The paraffinic AN-F-58 (48-249 and 48-258) blends allow higher altitude limits than AN-F-28; however, increasing the aromatic content of AN-F-58 to 29 percent (48-279) lowers the altitude limits of this fuel approximately 3000 feet below AN-F-28 at the higher speeds. The combustion efficiencies obtained during these tests were highest for AN-F-28 aviation gasoline and decreased with increase in boiling range. This is illustrated by figure 5 in which the combustion efficiency for each fuel at a simulated altitude of 45,000 feet and a corrected engine speed of 12,500 rpm at a ram-pressure ratio of 1.04 is plotted against the 50 percent boiling point of the fuel. Six hour tests at 35,000 feet altitude and 87 percent of rated engine speed indicated that considerable carbon was formed in this combustor with the 29 percent aromatic fuel (48-279).

Nene I Combustor. - The altitude operational limits and the combustion efficiencies of AN-F-32 and the three blends of AN-F-58 fuel were obtained on the Nene-I single combustor at the inlet conditions simulating engine operation for a range of speeds from 40 to 100 percent rated, and at inlet Mach numbers of 0.0 and 0.6. Since the tests on the Nene combustor are incomplete the results are of a preliminary nature. Although the tests were conducted to the highest altitude permitted by the laboratory services, it was not possible to completely obtain the altitude limits of these fuels. For all conditions investigated, increasing the boiling temperature of AN-~-58, for a given aromatic content, slightly increases the altitude limits, whereas increasing the aromatic content to 29 percent apparently lowered the altitude limit except at very high speeds. At an inlet Mach number of 0.0, the 90 percent combustion efficiency values for the four fuels were no more than 4000 feet apart at speeds above 70 percent of rated. At an inlet Mach number of 0.6 the 90 percent combustion efficiency point of the higher boiling (48-258) and the high aromatic content (48-279) AN-F-58 fuels was about 5000 feet higher than 48-249. At all conditions increasing the aromatic content of AN-F-58 had little effect on the combustion efficiency of the Nene combustor.

## CONCLUSION

From the single combustor tests outlined in the previous discussion, the results indicate that fuels conforming to specification AN-F-58 can be used satisfactorily in current Jet engines utilizing can-type combustors. However, in the J-34 combustor AN-F-58 fuels showed increased tendencies toward carbon deposition and decreased combustion efficiencies when compared with AN-F-28 aviation gasoline.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, November 12, 1948.

TABLE I
AN-F-32 and
AN-F-58 FUELS

| | AN-F-32 specifi-cations | AN-F-32 48-306 | AN-F-58 specifi-cations | AN-F-58 socony-vacuum 48-249 | AN-F-58 special blends 48-258 | 48-279 |
|---|---|---|---|---|---|---|
| ASTM distillation | | | | | | |
| IBP °F | -------- | 336 | ---a--- | 110 | 112 | 110 |
| 5 (evaporated) | -------- | 349 | -------- | 135 | 137 | 133 |
| 10 | 410 | 355 | -1-w---- | 157 | 157 | 164 |
| :: | -------- | ---360-365 | --W---W-------- | 192 230 | 248 198 | 215 |
| | | | | | | 273 |
| 40 | -------- | 370 | -------- | 272 | 291 | 327 |
| 60 | -------- | 375 | -------- | 314 | 332 | 370 |
| 70 | -------- | 381 387 | ----I---- | 351 388 | 373 | 407 |
| | | | | | 410 | 437 |
| 80 | | | | | | |
| 90 (min) | -------- | 490 394 | 405-------- | 425 473 427 | 450 500 | 464 501 |
| FBP (max` % (max) | 572 | 446 | 600 | 560 | 590 | 590 |
| Residue (max) | 1.5 | 1.0 | 1.5 | 1.0 | 1.0 | 1.0 |
| Loss, % | 1.5 | 1.0 | 1.5 | 1.0 | 1.0 | 1.0 |
| Freezing point, °F (max) | -------- | ------- | -76 | <-76 | <-76 | <-76 |
| Aromatics, vol. % (max) | | | | | | |
| ASTM D-875-46T | 20 | -------- | 30 | 17 | 17 | 26 |
| Silica Gel | -------- | 15 | -------- | 19 | 19 | 29 |
| Viscosity, centistokes | | | | | | |
| -40° F (max) | 10 | ------- | 10.0 | 2.67 | 2.94 | 4.26 |
| Bromine number (max) | 3 | ------- | 14.0 | 13.8 | 13.3 | 12.4 |
| Reid vapor pressure, | | | | | | |
| lb/sq in. | -------- | ------- | 5 to 7 | 5.4 | 5.1 | 4.8 |
| H/C | -------- | 0.154 | -------- | 0,163 | 0.161 | 0.150 |
| Heat of combustion, | | | | | | |
| btu/lb (min) | -------- | 18,530 | 18,200 | 18,640 | 18,690 | 18,480 |
| Specific gravity (max) | 0.850 | 0.831 | -------- | 0.769 | 0,775 | 0.806 |
| Sulfur, wt. % (max) | 0.20 | 0.02 | 0.5 | 0.035 | 0.043 | 0.045 |

NACA

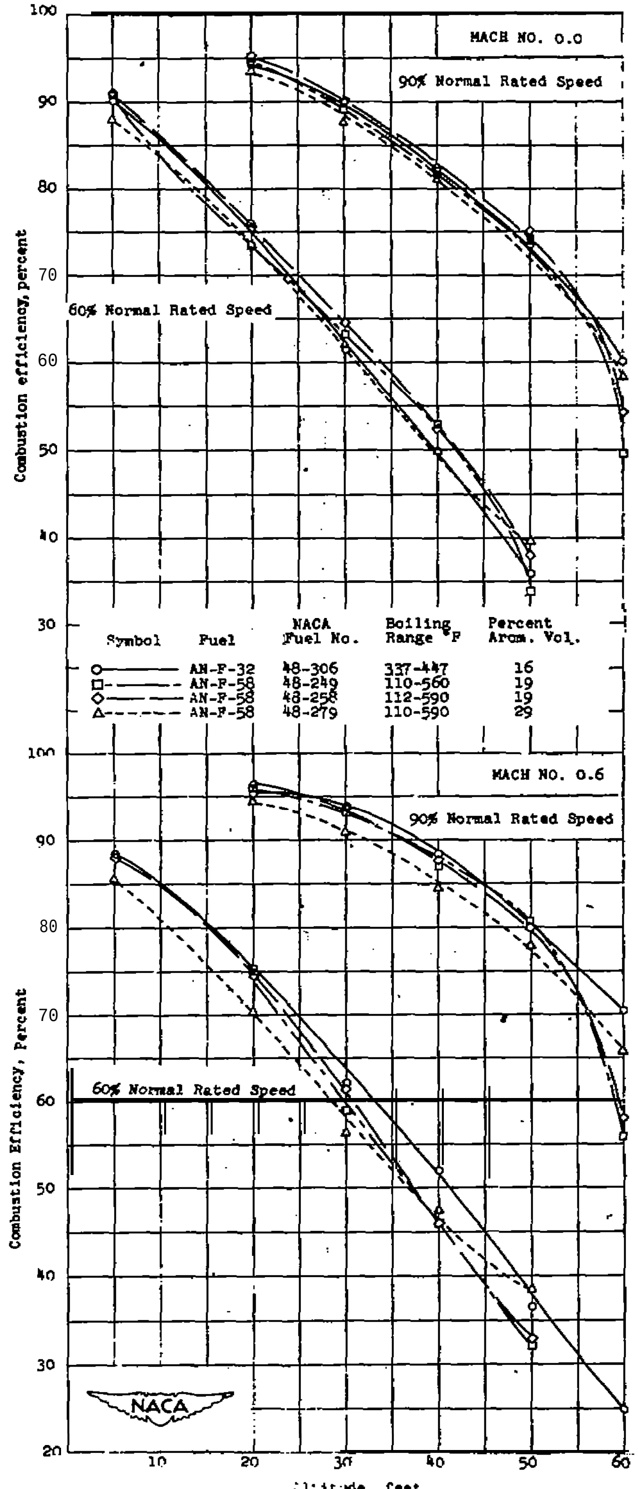



Figure 1 - Variation of Combustion Efficiency with Altitude in a Single J-33-A-23 Combustor for 4 Fuels at 60 and 90 Percent Normal Rated Engine Speeds for 2 Mach Numbers

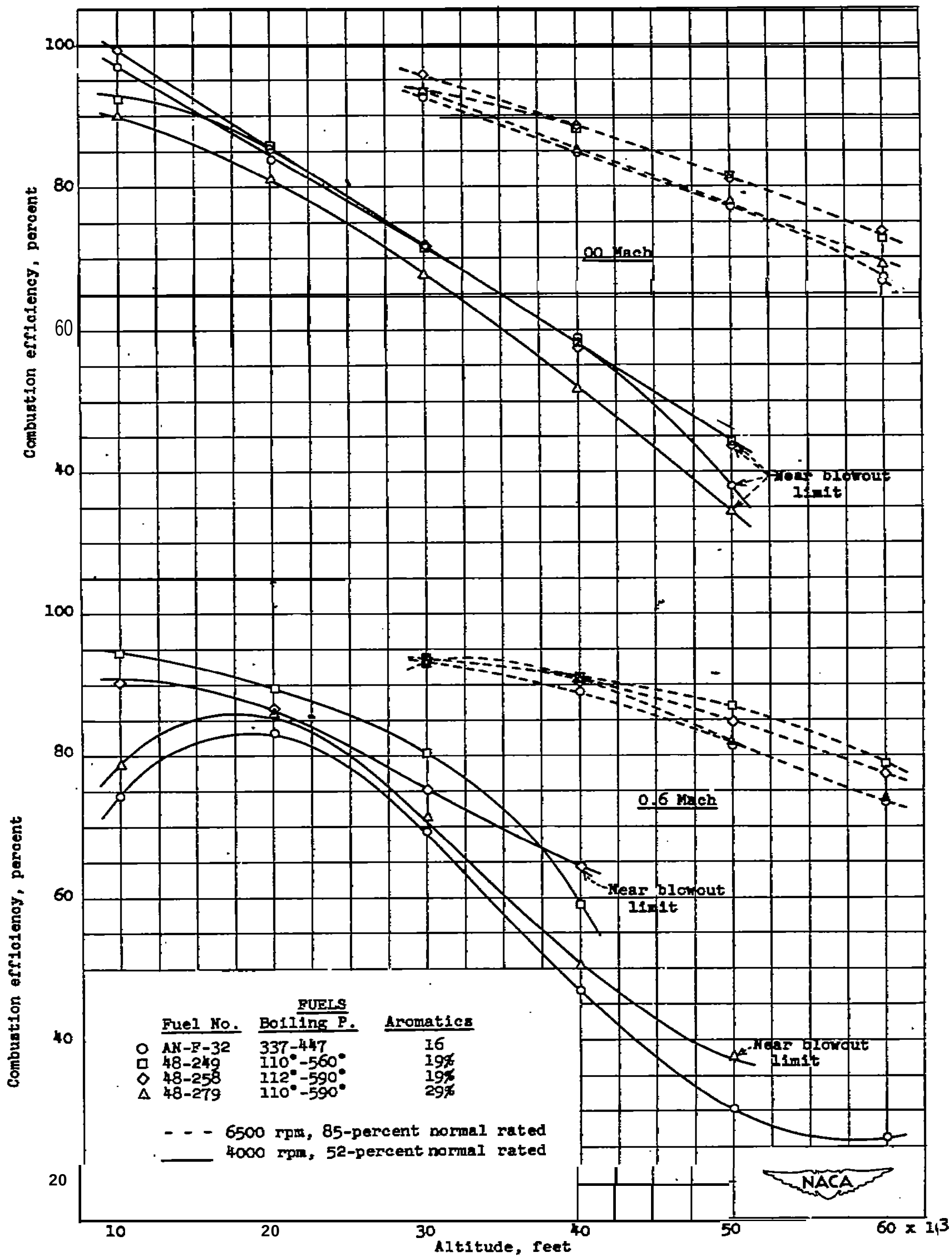



Figure 2, Effect of altitude on combustion efficiency for four fuels in a General Electric J-35 C combustor.

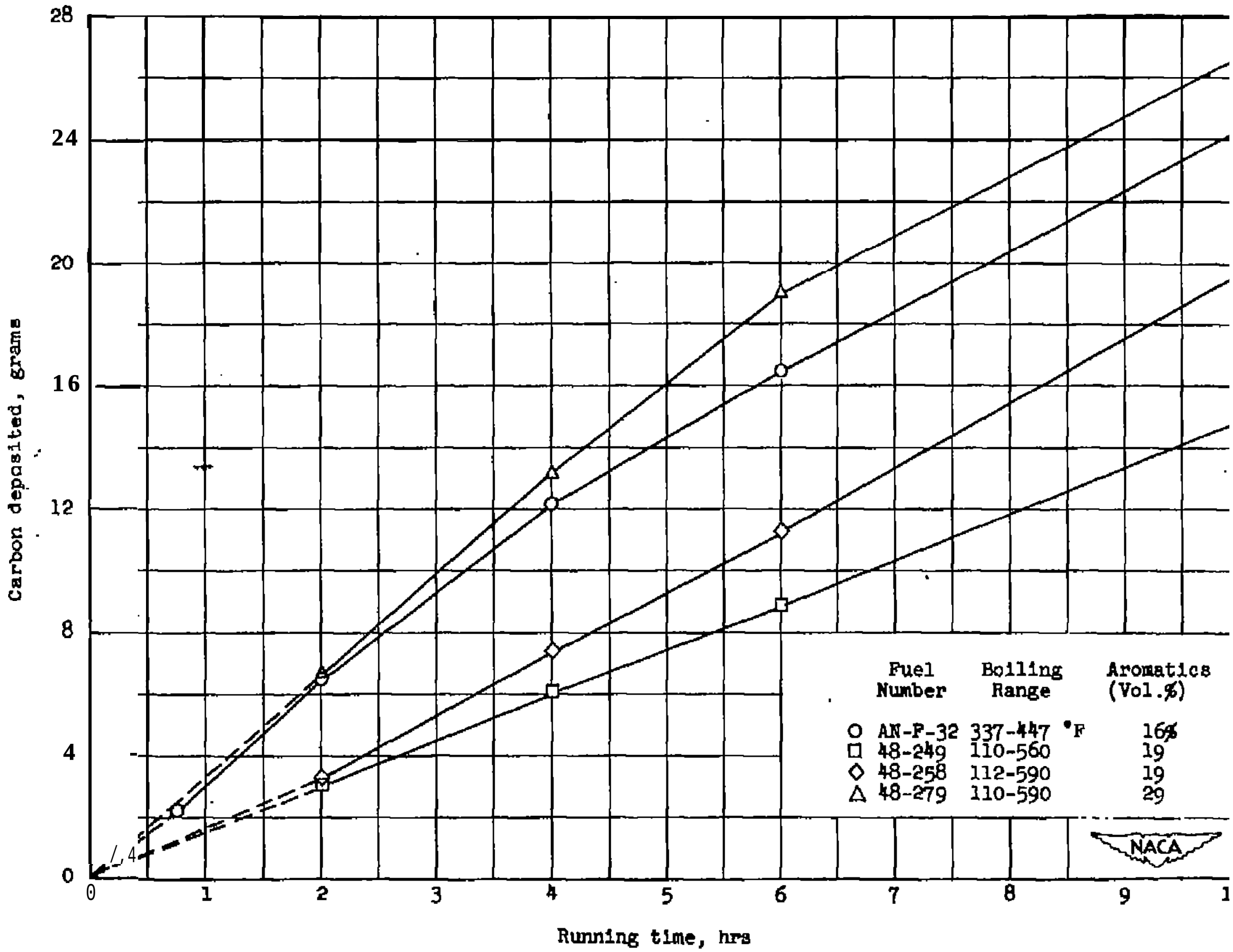



**Figure 3 -** The effect of running time on carbon deposition of Pour fuels in a J-33 single **combustor.** Simulated engine operating conditions; 90 percent of normal rated engine speed, 20,000 feet altitude, and zero ran.

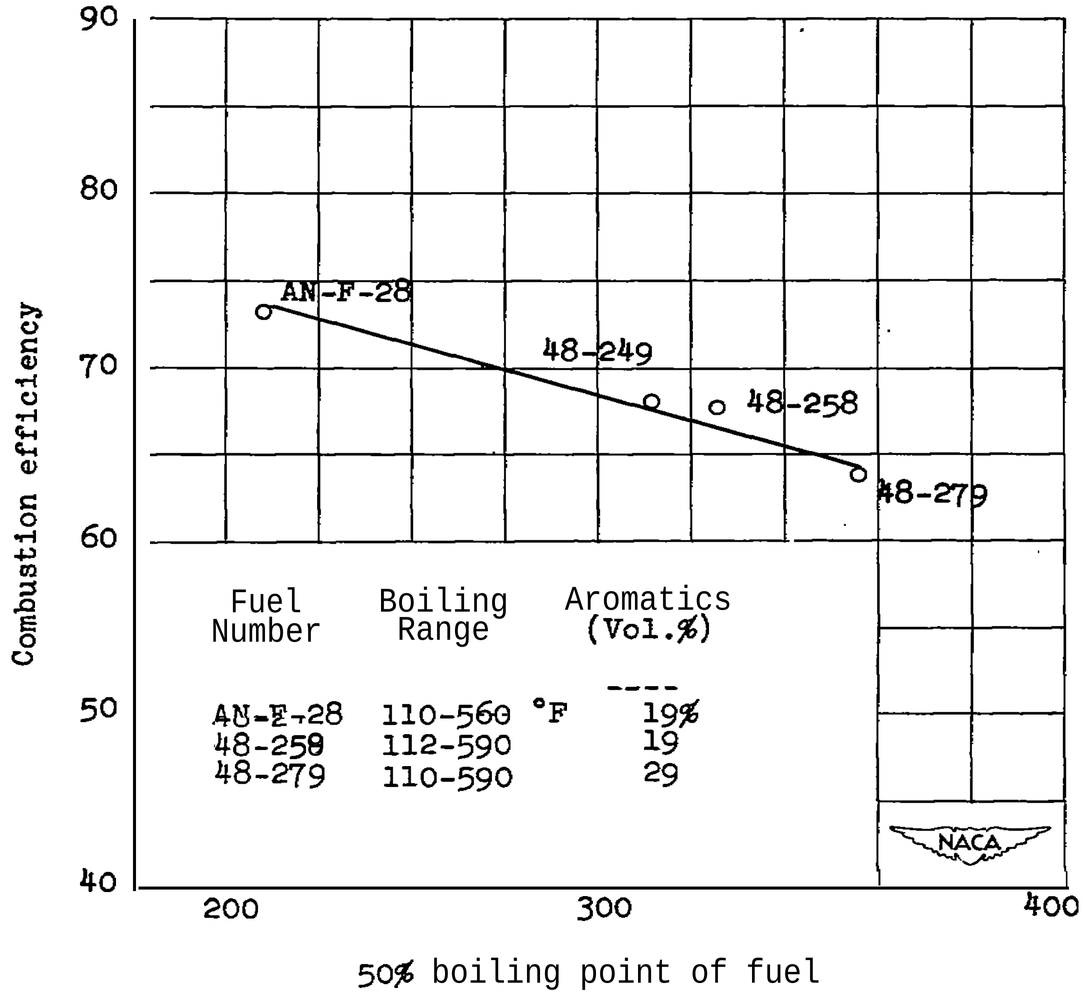
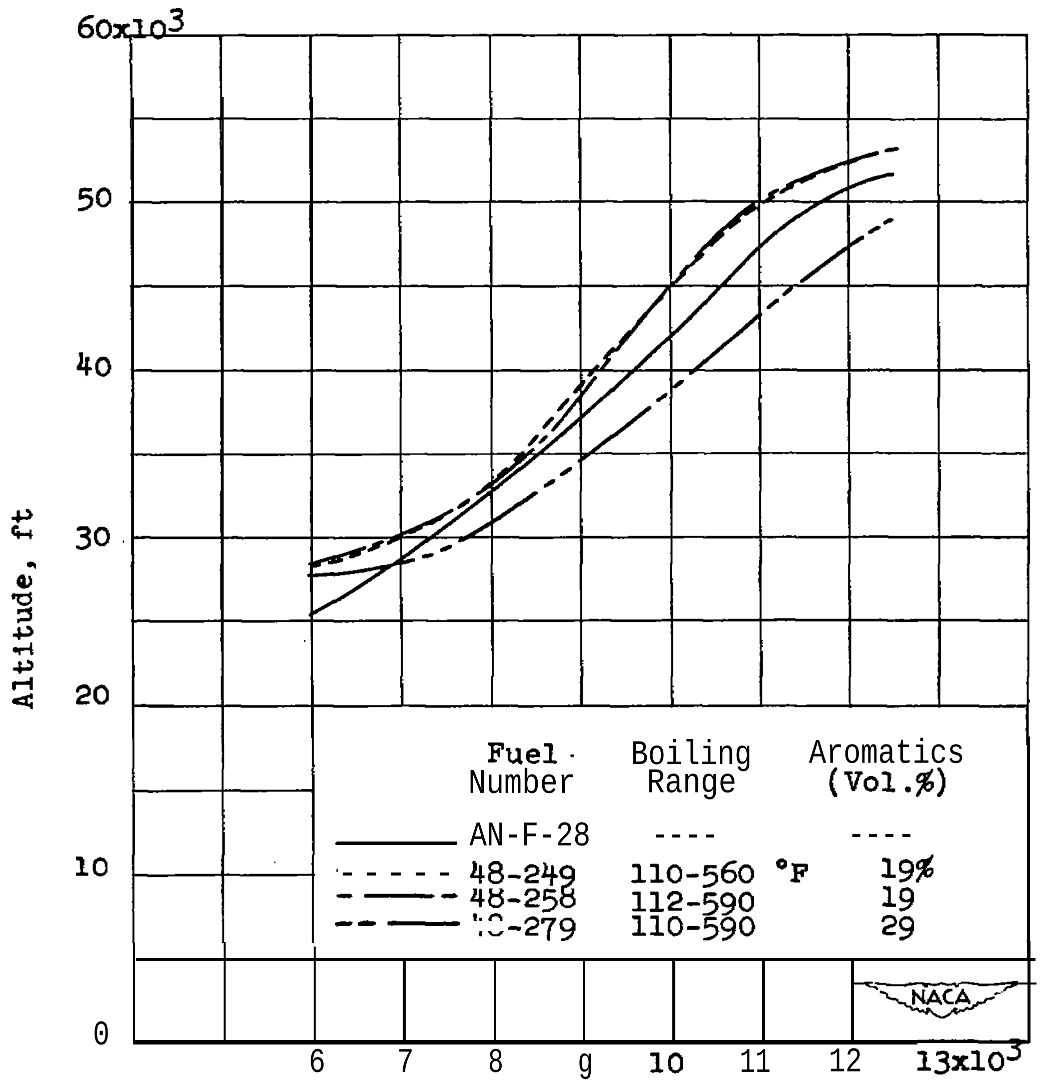



Figure 5 - Correlation of combustion efficiencies of fuels in J-34 combustor, at simulated altitude of 45,000 feet and corrected engine speed 12,500 rpm, and 50% boiling point of fuel by A.S.T.M. distillation.




Corrected engine speed, $N/\sqrt{\theta}$

Figure 4 - The estimated altitude operational limits for the J-34 single combustor at M = 0.25